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FEASIBILITY OF EPIDEMIOLOGIC RESEARCH ON NONAUDITORY HEALTH EFFECTS OF RESIDENTIAL AIRCRAFT NOISE EXPOSURE

Summary and Recommendations

Volume I of III Volumes

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This report has been reviewed and is approved for publication.

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This report examines the feasibility of conducting epidemiologic studies that would support inferences about effects of residential exposure to aircraft noise on nonauditory health. The type of aircraft noise of particular interest is that associated with supersonic and low altitude, high speed flight in Military Operating Areas (MOAs) and Military Training Routes (MTRs): both sonic booms and high peak level, rapid onset time subsonic noise. Potential studies considered are those with observational designs that are community-based or derived from audiometric databases. Since the primary goal of such studies is to improve the Air Force's ability to predict the effects on nonauditory health of noise exposure near MOAs and MTRs, such studies must provide: a demonstration of a causal chain from aircraft noise exposure to nonauditory adverse health consequences; and a reliable quantitative relationship between amount of noise exposure (dose) and degree of specific health consequences (effect). [illegible]

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Table of Contents

Foreword

This report was prepared under Contract F33615-86-C-0530 of the Noise and Sonic Boom Impact Technology (NSBIT) program. The NSBIT program is conducted by the United States Air Force Systems Command, Human Systems Division under the direction of Captain Robert Kull, Jr., Program Manager. Mr. Lawrence Finegold was the contract monitor for this effort.

The work reported herein describes effort completed under Task Orders 0007 (started 7 July 1987), 0011 (started 25 September 1987), and Subtask 20.6 (started 12 April 1989).

This report is divided into 3 volumes. Volume I is an executive summary of the detailed findings of Volume II. Volume III contains a tabular summary of the literature on the effects of noise on health.

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Executive Summary

Residential aircraft noise exposure has been alleged to be associated with adverse health effects ranging from blood pressure changes to mental hospital admissions, increased drug use, birth defects, and even death (Cohen et al., 1980; Jenkins et al., 1979; Knipschild and Oudshoorn, 1977; Jones and Tauscher, 1978; Meecham and Shaw, 1979). Most studies that have led to the inference of adverse effects of noise exposure on health are seriously flawed in design, and many in execution. Credible evidence about effects of noise on health is largely inconclusive, and tends to deal with levels and circumstances of exposure quite different from residential exposure to aircraft noise.

Nonetheless, the Air Force must often respond, sometimes in politically charged circumstances, to claims of nonauditory health effects of noise exposure produced by its flight operations. The need to find more persuasive responses has grown as the recent trend toward increased training of aircrews in low altitude flight operations has created greater residential noise exposure, often in areas remote from airbases.

This report is intended as a planning and background document for development of an Air Force strategic research plan on the effects of aircraft noise on health. The current plan complements the NSBIT Management Plan, since it was developed without regard to the time and resource constraints of the earlier plan. This document (1) describes options available for conducting useful studies of the effects of residential aircraft noise exposure on health, (2) evaluates the relative merits of various approaches to the problem, and (3) recommends a strategy to guide the conduct of research in this area.

1. Introduction

Residential aircraft noise exposure has been alleged to be associated with adverse health effects ranging from blood pressure changes to mental hospital admissions, increased drug use, birth defects, and even death (Cohen et al., 1980; Jenkins et al., 1979; Knipschild and Oudshoorn, 1977; Jones and Tauscher, 1978; Meecham and Shaw, 1979). Many such allegations are based on meager scientific evidence and are highly speculative. Although a large body of research treating the effects of noise on physical and psychological health has accumulated over the last few decades, even the best of this work fails to provide clear evidence of adverse health effects. Much of the research has concentrated on health effects of high level, long duration, continuous noise exposure in the workplace, rather than on intermittent residential exposure to transportation (aircraft and traffic) noise. Even so, there has been no clear demonstration of adverse extra-auditory effects of residential aircraft noise exposure.

Nonetheless, the Air Force must often respond, sometimes in politically charged circumstances, to claims of consequential health effects of noise exposure produced by its flight operations. Although there are excellent reasons to believe that residential aircraft noise exposure does not pose a meaningful hazard to health, the Air Force cannot for various reasons cite conclusive evidence to support this view.[1] Instead, the Air Force must respond to allegations of adverse health consequences of aircraft noise exposure primarily by documenting the logical, procedural, and statistical flaws of published studies. The need to find more persuasive responses has grown more urgent as the recent trend toward increased training of aircrews in low altitude flight operations has created greater residential noise exposure, often in areas remote from airbases.

The need for such low-flying, high speed operations, including some at night, is expected to increase markedly in the near future. These operations will produce increases in both maximum sound levels and flyover onset times, both of which may accentuate startle effects. Maximum sound levels (weighted for sensitivity of human hearing) of low altitude, high speed flights can exceed those in the vicinity of civil airports by 15 dB or more. Onset times in the airport case rarely exceed 5 dB/s, whereas low altitude, high speed flight can create flyovers with onset times as great as 70 to 80 dB/s, little different from the rise times of sonic booms.

The National Environment Policy Act (NEPA) of 1969 requires the U. S. Air Force to predict the effects of its aircraft operations. Major changes in military operations now require

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[1]These reasons include the reluctance of most researchers to undertake studies in which the most likely outcomes are findings of no effects; the reluctance of journals to publish articles which report an absence of findings; and the near-impossibility of demonstrating the complete safety of exposure to any environmental agent.

environmental impact statements, which in turn require prediction of the effects of those changes, including potential adverse health consequences of aircraft noise exposure on residential populations.

Although many documents offer guidance in the preparation of impact statements (e.g., CHABA, 1977, 1981, 1982; Galloway, 1981; EPA, 1973, 1974, 1980, 1982, USAF, 1984; Departments of the Air Force, the Army, and the Navy, 1978; NATO, 1988), they generally refer to studies which report inconclusive findings about the effect of noise on nonauditory health. Most guidance documents explicitly note the lack of useful data and the need for further research.

Given the need for environmental impact statements and the fact that the Air Force has had only limited success in countering claims of health hazards of residential aircraft noise exposure by analytic means alone, there may be merit in undertaking empirical studies which are well enough designed and executed to produce definitive findings. This document (1) describes options available for conducting scientifically valid studies of the effects of residential aircraft noise exposure on health, (2) evaluates the relative merits of various approaches to the problem, and (3) recommends a strategy to guide the conduct of research in this area.

Chapter 2 of this volume provides background information about the nature of health effects of residential aircraft noise exposure and investigations of them. Chapter 3 identifies goals for a research program, while Chapter 4 evaluates alternative means of reaching these goals. Chapter 5 contains a plan for a research program that can satisfy the present goals.

2. Background

It is helpful to make explicit some of the principal constraints on the design of credible studies of the health effects of residential aircraft noise exposure before discussing detailed research strategies. A Glossary may be found after Chapter 5 to assist readers unfamiliar with acoustic, epidemiologic, and physiological terms.

2.1 Nature of Noise Effects on Health

There is no doubt that noise can affect people physiologically in varying degrees, producing responses ranging from transient elevations of pulse rate and blood pressure to long term hearing damage.[2] Extra-auditory physiological responses of this sort are not, however, specific to aircraft noise exposure, and are generally considered as signs of unremarkable homeostatic processes. It is only when the intensity and duration of nonspecific physiological responses become extreme that they may be regarded as pathological.

For reasons discussed in Volume II, the weight of the evidence suggests that if residential aircraft noise exposure can in fact be linked to long term adverse health consequences, the cardiovascular system is the most likely physiological system in which such consequences might be detected. Among the more common findings of cross-sectional and ecologic studies reviewed in Volume II are slight elevations in systolic blood pressure (SBP) or diastolic blood pressure (DBP). Mean increases as great as 6 mm Hg in DBP and 9 mm Hg in SBP, and unadjusted prevalence ratios of 1.5 to 1.7 for high noise relative to low noise exposure, have been reported in such studies. Considering that DBP in the general population of healthy adults has a log normal distribution with a mean of about 80 mm Hg and a standard deviation of roughly 15 mm Hg, and that SBP is similarly distributed with a mean of about 120 mm Hg and a standard deviation on the order of 20 mm Hg, these changes of less than half a standard deviation cannot be considered very alarming, particularly when it is unknown whether they are transient or persistent changes.

It is clear from the literature reviewed in Volume II that effects of noise on nonauditory health, if they exist at all, are subtle, long term, and indirect. Any linkage between residential

[2]Noise induced hearing loss is not a plausible consequence of residential exposure to aircraft noise, however, since the duration, absolute level, and frequency of occurrence of aircraft noise intrusions indoors are insufficient to damage hearing.

aircraft noise exposure and cardiovascular damage is almost certainly mediated by psychosocial and other nonacoustic factors. The most plausible means for production of disease from residential aircraft noise exposure is through annoyance, which could arguably cause an unknown degree of physiological stress that might eventually adversely affect cardiovascular function by incompletely understood means.

2.2 Examples of Recent Studies of Health Effects of Aircraft Noise Exposure

One type of aircraft noise exposure of recent concern is that produced by high speed, low altitude flights along military training routes (MTRs) in low population density areas of the United States and in higher population density areas in Europe. Such flights produce noise intrusions with very rapid onset times which may startle people more than aircraft noise intrusions with lower onset times common in airport environs.

The first report of physiological responses to rapid onset time noise exposure from high speed, low-altitude flight is that of Ising and Michalak (1988). Ising and Michalak studied effects in the elderly and in school children of increases in noise levels of 30 dB in less than 0.5 s and L_{max} values above 110-115 dBA. In the first study, 24 volunteers between 70 and 88 years of age were exposed via earphones to two types of recorded flight noise: noise with level increases of 30 dB within 4 s, and noise with level increases of 30 dB within 0.4 s. Significantly higher blood pressure increases were observed in response to earphone presentation of the rapid onset time flight noise than to the more gradual onset time noise.

In a second study, cross-sectional data were obtained from 430 children in villages within a 75 m low level flight area and in a neighborhood in a 150 m low level flight area. Maximum noise levels reached 125 dBA in the two communities. Girls' mean systolic blood pressure, but not boys', was 9 mm Hg higher in the area in which lower altitude flights were permitted. Since few details of the study are reported, it is difficult to evaluate these findings in the context of chronic exposure to low level flights.

Another type of aircraft noise exposure that has produced health-related controversies for both the Air Force and the Navy is sonic booms. The Air Force recently sponsored an epidemiologic study (Anton-Guirgis et al., 1986) which was unable to produce clear evidence about potential relationships between sonic boom exposure and adverse health effects in residents of the State of Nevada, where supersonic flight operations have been carried out since 1969. Data on mortality and morbidity by five categories (cardiovascular, hypertensive, cerebrovascular accident, cancer and other causes) were collected from Nevada vital and death records and from annual hospital discharges from 20 of the 33 licensed hospitals in the state.

Estimates of sonic boom environments in Nevada from 1969 to 1983 were based on analyses of historical and computerized records of supersonic operations. The estimated annual C-weighted DNL due only to sonic booms was spatially averaged over each township in the state (Kamerman et al., 1986, p. 62). The space-averaged L_{Cdn} values ranged from 0 to 56 dB in the townships. The average sound level for each township across the period of 1969-1983 was calculated by dividing the sum of L_{Cdn} values across years by 15. Townships with an average L_{Cdn} greater than 36 dB (upper one-third) were classified in the high noise area[3]; those with average sound levels less than 31 dB (lower one-third) were classified in the low noise area; and the remaining townships were grouped in an intermediate exposure area.

Since township populations could not be partitioned by race, sex, or age, adjusted morbidity/mortality rates could not be estimated. County level data showed that crude rates of mortality increased systematically from low exposure to high exposure areas. However, no consistent relation was observed for overall mortality or for cause-specific mortality when the rates were stratified by sex and adjusted for age. A trend analysis over time showed that noise exposure as measured by L_{Cdn} increased over the time period. Over the same time period there was a decline in all-cause age-adjusted mortality, inconsistent changes in age-adjusted cardiovascular, hypertension and cerebrovascular accidents and an increase in cancer mortality. Bivariate linear regression between sonic boom exposures and mortality revealed no consistent pattern of relationships for any cause.

Several problems are apparent in the Anton-Guirgis et al. (1986) study, including:

- difficulties in relating mortality and morbidity data to relatively small geographic areas (such as townships) which could be classified by noise exposure;
- absence of empirical measurement of noise exposure;
- difficulty in obtaining and relating population data by age, race, and sex to the desired township exposure unit which led to use of a larger unit, the county (which may have diluted any effect because it included several exposure levels);
- the usual difficulties in deriving meaningful inferences from ecologic analyses of vast geographic areas where the population at risk is relatively small.

The meaningfulness of these and other findings about health consequences of noise exposure is discussed more fully in Volume II of this report.

[3]Wind noise alone is capable of producing L_{Cdn} values of comparable magnitude.

2.3 Factors Complicating the Study of Health Effects

Chief among the obstacles hindering design of studies of health effects of residential aircraft noise exposure are the following:

- incomplete understanding of biological mechanisms and the clinical significance of potential effects of noise exposure;
- difficulties in measuring and estimating long term, source-dependent personal exposure to aircraft noise;
- the long latency period and small magnitude of the more plausible (cardiovascular) effects;
- the difficulty of controlling or otherwise accounting for the effects of numerous confounding and intervening variables;
- the paucity of sites at which adequate populations of exposed and nonexposed persons can be distinguished and studied;
- the ethical and pragmatic impossibility of conducting controlled experimental investigations and/or controlled interventions in the populations and exposure circumstances of greatest relevance; and
- the difficulty in demonstrating the *absence* of an effect, since studies which fail to find a relationship between noise and health are subject to the criticism of imperfect design.

The practical consequences of these obstacles are formidable. They imply, for example, considerable risks of misclassification bias, ecologic fallacies, and low statistical power due to small samples. All of these contribute to serious logical and statistical problems in interpreting findings. They also imply that credible findings require costly, long term, and technically difficult studies.

Consider, for example, the difficulties inherent in efforts to quantify the independent variable (noise) for any epidemiologic study of the health effects of residential aircraft noise exposure. Problems of acoustic measurement of aircraft noise exposure for epidemiologic purposes may be summarized as follows:

- The most persuasive form of direct measurement is continuous, long term, source-specific individual noise doses (dosimetry). This form of measurement of acoustic exposure is the only one consistent with the individual as the unit of analysis[4], and the only one capable of distinguishing aircraft noise from other noise exposure

[4]Either individuals or groups defined by geographical area can serve as the unit for statistical analysis in epidemiologic research. The individual is the preferred unit of analysis.

sources. It is also technically difficult and expensive to accomplish this type of measurement, even on a limited scale.

- Given that this kind of measurement of aircraft noise exposure is unlikely to be economically or technically feasible on a useful scale, the next best form of quantification of exposure is wide area, outdoor measurement. Such measurement is a distinct second-best, however, since it is inconsistent with epidemiologic analyses of individual effects, and invariably introduces the ecologic fallacy (the assumption that outdoor noise measurements reflect individual noise exposure levels) into study designs. Place measurements must usually be supplemented with questionnaire information confirming the presence of individuals at particular times and locations and documenting other noise exposure.

- The third-best method of quantifying aircraft noise exposure is by estimate and assumption. For some types of retrospective studies this is the only form of quantification of exposure that is possible. Reconstruction of historical noise exposure patterns can only rarely be accomplished with the accuracy and precision needed to support valid epidemiologic inference, and introduces the possibility of serious misclassification bias.

- The least satisfactory method of quantifying noise exposure for epidemiologic research on aircraft noise exposure effects is by measurement of a surrogate variable such as hearing loss.

In short, the problems of acoustic measurement for epidemiologic studies of aircraft noise effects on health are consequential and intractable in some cases.

2.4 Research Methods for Studying Health Effects

Three basic approaches to the study of health effects of aircraft noise exposure can be identified: (1) an epidemiologic approach, in which evidence is sought in community-based or other etiologic studies of differences in specified health conditions between exposed and nonexposed populations; (2) a clinical approach, in which closely controlled short term observations are made of relatively small numbers of people adventitiously or otherwise exposed to aircraft noise; and (3) a physiological approach, in which experiments may be performed on animals to clarify biologic mechanisms and demonstrate the effectiveness of interventions. The current effort focuses on epidemiologic designs because:

- Basic information produced in clinical studies is less useful to environmental planners than that produced by epidemiologic studies. Clinically-derived information cannot be directly used to predict rates of adverse health effects of aircraft noise in residentially exposed populations, nor is it helpful in refuting many forms of allegations about health hazards of aircraft noise exposure.

- Information produced in laboratory studies of effects of noise exposure on animals

is the least useful sort of information for environmental planners, since it is so basic in nature that it cannot be readily applied to the particular circumstances of an environmental impact assessment.

The most common objective of epidemiologic study is to define cause-effect relationships by associating particular exposures with potential health effects which are highly unlikely to be attributable to any other differences between exposed and nonexposed populations. An etiologic association between noise exposure and disease is most simply shown in a binary fashion, by demonstrating a statistically significant difference in incidence of a given disease in exposed and nonexposed populations.

Epidemiologic studies may be classified as experimental or observational. In experimental studies, individuals are randomly assigned to exposure and nonexposure in an unbiased (often randomized) manner. In observational studies, nature is allowed to take its course and changes or differences in one characteristic are related to changes or differences in the other, if any. Unfortunately, it is difficult in observational research to distinguish effects potentially produced by aircraft noise exposure from those produced by other forms of noise exposure (aircraft noise is only one of many sources of individual noise exposure, and not necessarily a dominant one). It is similarly difficult to distinguish effects produced by factors other than noise, and to determine the relative contributions of different factors to production of disease. A major strength of epidemiologic observational studies relative to most experimental research, however, is that they apply directly to human beings.

Experimental studies in which humans are randomly assigned to environments with varying degrees of aircraft noise exposure for long periods of time are obviously not feasible for practical and ethical reasons. It is also impractical to conduct controlled intervention studies of communities (1) in which the characteristics and health of the population are well specified before exposure begins and/or after exposure ends, (2) where a specific and significant long term change in aircraft exposure can be anticipated and verified, and (3) where the health outcome can subsequently be determined.

2.5 General Process Model

Chapter 4 in Volume II develops a general process model that identifies independent, intervening, and dependent variables that can arguably be linked to form hypothetical causal chains between aircraft noise exposure and adverse effects on human health. Two requirements must be met for Air Force environmental impact analyses to present convincing predictions of health consequences based on causal chains of reasoning. First, a cause-effect relationship

(health consequence) must be shown. Second, a quantitative dosage-effect relationship must be established that shows amount of change in health outcomes as a result of amount of change in exposure.

A useful general process model requires specification of the aspects of noise exposure, the other confounding variables that can vary along with noise exposure, the intervening and mediating psychological and physiological processes, and the health consequences, all in sufficient detail that testable hypotheses can be stated. This is a difficult chore given (1) the diffuse nature of the inferences that can be drawn from the literature on health effects of noise exposure; and (2) the paucity of evidence that noise exposure exerts a measurable influence on extra-auditory health.

After a review of literature on nonauditory-system response to noise and effects on health, Kryter (1985, p. 506) argues for an indirect pathwav through psychosocial factors. Such a view implies that noise is not inherently harmful, but only potentially harmful if it is found to be annoying. This increases the complexity of evaluations of the health consequences of aircraft noise by adding the challenges of measuring potential mediating and intervening psychological processes to the complexities of assessing exposure to noise and links between physiological responses and disease. The process model implies that an adequate evaluation of the link between aircraft noise and physical health will need to include the assessment of cognitions regarding threat, control, and helplessness; health-related coping; and traits such as neuroticism and Type A. Such an evaluation requires a sample large enough to allow for the possibility that noise exposure that is potentially harmful to one person is merely noise to another.

3. Research Goals

The current effort to develop a research plan is not the first that the Air Force has sponsored in the area of nonauditory health effects of noise exposure. In fact, the Air Force's interests in such effects can be traced to the early 1950s (Ades et al., 1953). The NSBIT program has itself produced previous program plans which recommend health effects research.

Other federal agencies and foreign governments have at various times recommended study of potential effects of aircraft and other forms of noise exposure on health as well. Public Law 90-411, for example, mandated in 1968 that FAA concern itself with effects of sonic booms on people. FAA's 1970 research program plan (Bolt Beranek and Newman, 1970) identified both animal and human research on stress induced disease, and accorded intermediate priority to several of them. The Office of Noise Abatement and Control of the Environmental Protection Agency published a five year research plan (EPA, 1981) containing specific recommendations for health related research. Working Group 81 of CHABA (CHABA, 1981) has made broad recommendations for epidemiologic and other research on effects of long term exposure to noise. The Nordic Noise Group of the Nordic Council of Ministers has recently published an evaluation of "the needs for continued efforts" to conduct research on health and other effects of noise exposure (Andersson and Lindvall, 1988).

Although the Air Force has sponsored studies of effects of noise on health (cf. Kent et al., 1986; Anton-Guirgis et al., 1986) in the recent past, the current effort is the first feasibility analysis of epidemiologic studies of health effects of aircraft noise exposure conducted to date under NSBIT sponsorship. Much of the difficulty in ascertaining what research needs to be done to address the impacts of aircraft noise on human health is that practical recommendations depend heavily on program-specific goals and resources available for the intended research.

From a narrow technical perspective, the most valuable goal for present purposes is demonstration of either the existence or absence of a cause-effect relationship between residential aircraft noise exposure and adverse health consequences. Reaching this goal requires (among other things) identification of plausible biological mechanisms, which in turn requires major advances in basic understanding of interactions between the human central nervous system and the cardiovascular system. It is unlikely that such basic technical goals can be attained in the near future in any single research program, because current understanding of such fundamental matters is so incomplete.

Given that there is little point in recommending a research program with unattainable goals, less fundamental but still worthwhile goals appropriate to the needs of Air Force environmental planners are in order. These goals must balance the pressing needs of Air Force environmental planners, the scientific merit of potential studies, and available resources.

The highest priority goal for Air Force sponsored research of nonexperimental, community based study of human populations is to produce sufficient information to permit derivation of a quantitative dosage-response relationship which planners could use in preparing and defending environmental impact assessments.

3.1 Characteristics of Study Designs of Greater Utility

Study designs most likely to produce information useful to environmental planners have the following characteristics:

- they focus on the individual as the unit of analysis and include statistical controls for confounding variables;
- they permit causal inferences about the influences of aircraft noise exposure on prespecified cardiovascular health outcomes;
- they involve direct physical measurement of individual noise exposure; or in the absence of individual exposure measurement, well-documented place estimates of exposure for individuals supplemented as possible by independent confirmations of exposure;
- they are of a duration comparable to or longer than the latent and induction periods of diseases of interest (a period on the order of five to ten years in the case of cardiovascular disease);
- they investigate effects of the types of residential aircraft noise exposure that actually occur near MOAs and MTRs;
- they examine effects that occur in individuals with lifestyles typical of low population density areas; and
- they are powerful enough in terms of sample size and absence of bias to be highly likely to detect a consequential effect if one exists, and to have very low probabilities of producing spurious findings.

3.2 Characteristics of Study Designs of Lesser Utility

Study designs less likely to produce information useful to environmental planners have the following characteristics:

- they do not permit inferences about the influences of aircraft noise exposure on cardiovascular or other prespecified health outcomes;
- they investigate effects of noise other than the sort that occurs under naturalistic

conditions in residential settings near MOAs and MTRs, such as occupational exposure, contrived short-term exposure under laboratory or field conditions, or non-aircraft noise exposure;

- they do not support development of quantitative dosage-effect relationships;
- they do not directly measure noise exposure, but rely instead on estimate, assumption, or measurement of surrogate variables.
- they examine effects at the aggregate level rather than at the individual level;
- they focus on individuals residing in places other than low population density rural areas, or in occupational rather than in residential settings; and
- they have too little power to uncover a consequential effect, even if one were to exist.

4. Order of Preference for Study Types

Etiologically oriented, community-based epidemiologic studies should be strongly preferred for present purposes. Information gained from studies of human populations exposed under naturalistic conditions to aircraft noise is the most direct, relevant, and useful form of information that can be provided to Air Force environmental planners. Information produced in non-etiologic studies (e.g., studies based on ecologic and cross-sectional designs) is of lesser value. Such studies can at best generate hypotheses for further testing, which for reasons discussed extensively in Volume II, add little to existing understanding of the effects of aircraft noise exposure on health.

4.1 Community-Based Epidemiologic Studies

Several types of community-based epidemiologic studies may be identified, differing in venue, design, and nature of noise exposure. They range from case-control studies of acute past episodes of exposure to prospective cohort studies of chronic exposure effects. Since the minimum period for cardiovascular disease to occur and be detected after the causal action is probably on the order of 5 to 10 years, studies of comparable exposure durations are preferable to studies of shorter exposure durations.

Prospective cohort study designs are clearly preferable to case control designs since they offer the greatest opportunities for making well controlled observations of both noise exposure and health consequences.

4.1.1 Studies of Effects of Exposure to MTR/MOA Noise

The most appropriate sites for community-based studies are in the vicinity of one or more MTRs and MOAs, because the noise of low altitude, high speed overflights and sonic booms seem to have the greatest potential for creating adverse health effects, and are of the greatest concern to Air Force environmental planners.

Required sample sizes for such studies are strongly influenced by study design, tolerable error rates and desired power for detecting effects, the degree of potential misclassification bias, expected drop-out rates, and the relative risk of disease, as discussed in greater detail in Volume II. An approximate lower bound on reasonable sample sizes is on the order of five hundred people (for case-control studies of strong effects with moderate power, little misclassification

bias, and lenient error rates). On the other hand, many thousands of people could be required for long term cohort studies of weak effects employing more stringent error rates. Only with very large samples is it possible to defend against the criticism that a failure to find an effect is due to low statistical power.

Since MOAs and MTRs in the United States are generally situated in areas remote from population concentrations, it is difficult to find domestic sites for conduct of such studies. It also may be difficult to find overflown communities in which residents and hospital personnel agree to cooperate with the Air Force in epidemiologic research on the effects of overflights on nonauditory health, and for which similar, nearby, unexposed, cooperative towns can be found. Low altitude, high speed overflights and sonic booms are, however, audible to residential populations elsewhere, including Germany, Great Britain, Turkey, and Israel among other places.

4.1.2 Studies of Effects of Exposure to Airport and Airbase Noise

If no sites can be identified at which it is feasible to conduct prospective cohort studies in the vicinity of MTRs or MOAs, it would be worthwhile to study health effects of aircraft approach and departure noise at civil airports or military facilities. Although this sort of noise exposure differs from that produced by operations near MOAs and MTRs, it is at least aircraft-related.

Effects of aircraft noise in the vicinity of airports and airbases may be productively studied either retrospectively or prospectively. Prospective cohort designs offer many advantages in power, control, and reliability that make them preferable to retrospective designs. Prospective designs can permit detailed analyses of individual noise exposure, but lack some of the cost saving efficiencies of case-control studies.

4.2 Studies of Surrogate Variables

If community-based epidemiologic study of health effects of residential aircraft noise exposure prove infeasible, it is possible in principle to study effects of occupational noise exposure effects through a surrogate for noise exposure: hearing damage. The most likely sources of data for epidemiologic analyses of occupational noise exposure effects (not necessarily from aircraft) are large databases of audiometric and other health information

maintained by the military services.[5] Although it is not possible to make direct use of analyses of information in audiometric databases to establish causal, quantitative dose-response relationships between residential noise exposure and health outcomes, such studies are nonetheless of some indirect utility to environmental planners.

A typical study of this sort would employ a retrospective cohort design to investigate the relationship between duration of noise exposure and the onset of hearing loss and blood pressure changes, while controlling for confounding factors. For example, the work of Kent et al. (1986) on the association between hearing damage and cardiovascular health in Air Force pilots could be extended, or similar studies might be conducted at other DoD facilities such as the Naval Air Rework Facility in San Diego. A group of workers employed at this facility during a specified time period could be classified by occupational category, while assumptions could be made about their personal noise exposure through place-oriented exposure estimates. It is possible that one or more such cohorts with differential noise exposure could be followed historically through time by examining medical records (as available) through NOHIMS, the Navy's occupational hygiene record keeping system.

Similar studies could in principle be designed to take advantage of expected improvements in other occupational health information systems maintained by the Air Force and Army. Certain limitations of such studies must be kept in mind, however, including the following:

- Difficulties can be anticipated in finding sufficient numbers of workers who can be followed though such databases for a long enough period of time to observe major changes in cardiovascular health status, and for whom relevant health information is complete;
- Many of the records available in such databases are those of young people in good general health, rather than of those at higher risk of developing cardiovascular disease attributable to noise exposure; and
- Military occupational hygiene databases are currently in the process of major upgrades; until these improvements are completed in several years, considerable difficulties of the sort encountered in previous studies can be expected in accessing and linking audiometric and health records.

One major difficulty in the use of hearing loss as a surrogate for noise exposure is the lack of research showing that hearing loss is indeed an adequate surrogate for exposure. Perhaps the most efficient immediate use of audiometric databases is to support such studies. Some possibilities include:

- A study which uses the same cohort as Kent et al. (1986) can be designed to address

[5] Similar information collected by private industry is less accessible, complete and reliable than that maintained by the military.

the question of whether hearing loss adequately mimics noise exposure in studies of effects on cardiovascular effects. Such a study could be conducted if exposure data on those in the cohort are complete enough to allow classification into exposure categories.

- It may be feasible to conduct a prospective cohort study of noise exposure and blood pressure changes using the HCDR database (see Volume II) linked with other health databases. This would offer an opportunity to further explore the relationships among noise exposure, hearing loss, and blood pressure changes.
- When deployed, portions of the Army OHMIS database may offer a basis for studying the link between hearing loss and blood pressure. Such a study could provide useful information to Air Force planners if hearing loss is demonstrated to be a reasonably good surrogate for noise exposure.

5. Suggested Research Plan

This chapter assigns priorities to the conduct of the various study types discussed earlier to provide information of use to Air Force environmental planners.

5.1 Assignment of Priorities

Volume II summarizes the ability of potential studies of health effects of noise exposure to meet both technical and practical criteria of utility to environmental planners. Considered in detail are various forms of prospective and retrospective community-based epidemiologic studies near MOAs, MTRs, civil airports and military airbases, as well as surrogate variable studies of occupational noise exposure.

Recommendations for determining the order of conduct of studies require criteria for establishing priorities. The basic criterion adopted for present purposes is utility of information produced by studies to Air Force environmental planners. This criterion permits a ranking which assigns the highest priority to study designs that can yield unambiguous information about the health consequences of the types of aircraft noise exposure created near MOAs and MTRs on the types of populations residing near them. It assigns the lowest priority to study designs that yield information less directly useful to environmental planners: that is, information about the effects of types of noise other than aircraft noise in non-residential circumstances of exposure.

Several uncertainties preclude identification of a definitive program of study at the time of this writing. For example, not all of the practical constraints on the feasibility of certain studies are currently apparent, and the resources available to support studies are also unclear. A research plan is therefore suggested which is contingent on the outcomes of feasibility analyses for several high priority studies. If such studies prove feasible, they should be implemented; if they prove infeasible, the decision to undertake the next highest priority studies must be made by weighing the value to environmental planners of the information that could be produced against the cost of obtaining the information.

5.1.1 Studies of Highest Priority

The highest priority research design is a prospective community-based epidemiologic study of the health effects of residential exposure to aircraft noise in the vicinity of domestic MTRs and MOAs.

Chapter 6 of Volume II describes the results of a feasibility analysis to determine whether it is reasonable to attempt such a study. It was concluded that such research is indeed feasible under the following conditions:

- The study should be conducted in several communities which are in the vicinity of MTRs, MOAs, and supersonic ranges. Several such communities are identified in Volume II.
- Catchment areas and sizes for health/medical facilities most likely to be used by selected communities must be ascertained.
- Willingness of medical personnel to cooperate in long term epidemiologic study must be ascertained.
- Direct measurement of noise exposure in communities selected to represent exposed as well as unexposed populations is essential, preferably on an ongoing basis throughout the duration of the study.
- Communities must be willing to cooperate over a long period of time with monitoring procedures which offer no direct benefits to participants and are often inconvenient and time consuming.
- A long term (5-10 year) commitment to continued military flight operations is required.

Should the foregoing study prove to be technically or financially impractical, an analysis should be undertaken of the feasibility of conducting a prospective cohort or case-control study of health effects of exposure to aircraft noise exposure in the vicinity of a foreign MTR.

Such an analysis would require about six months to complete. The study would necessarily have higher costs than those incurred for a domestic study, due to the necessity for coordination with foreign authorities and travel.

If the above investigations show that an epidemiologic study in the vicinity of a domestic or foreign MOA or MTR is feasible, then such a study should be undertaken. Costs and durations for such studies would vary by study design.

If the above investigations show that such a study is not feasible, then the following feasibility investigations should be undertaken:

1. An investigation of the feasibility of undertaking a prospective or retrospective

cohort study of health effects of exposure to aircraft approach and/or departure noise in the vicinity of one or more large civil airports.

2. An investigation of the feasibility of undertaking a prospective or retrospective cohort study of health effects of exposure to aircraft approach and/or departure noise in the vicinity of one or more military airfields.

These two studies would each require about six months to complete.

If the above investigations show that an epidemiologic study in the vicinity of a civil airport or military airfield is feasible, then such a study should be undertaken. Costs and durations for such studies would vary by study design.

If the above investigations show that it is not possible to conduct a study in the vicinity of a civil airport or military airfield, then an appraisal should be made of the value to environmental planners of less direct information about noise effects on health, as suggested below.

5.1.2 Studies of Lower Priority

5.1.2.1 Surrogate Variable Studies

If no studies can be undertaken in which noise exposure may be directly measured or estimated with confidence, a feasibility analysis of a surrogate variable study employing a retrospective cohort design should be undertaken. The key issues for the feasibility analysis should be (1) identification of difficulties that can be anticipated in accessing records in audiometric databases, and in linking individuals' audiometric records with their records in other health databases containing information relevant to the hypotheses derived from the general process model; (2) characterization of the population of individuals available for study in the audiometric databases; and (3) estimation of the reliability and completeness of such information, and of the costs for software development needed to conduct the study.

If the conduct of one or more surrogate variable studies proves feasible, such studies should be undertaken in parallel.

5.1.2.2 Cessation of Military Activity

One of the difficulties inherent in conducting prospective epidemiologic research is the possibility that selected exposed communities may become ineligible over the course of the study as a result of lack of exposure, as could happen in the event of closure of an MTR, MOA, or airbase. Should such an event occur, however, a prospective change study could be designed to take advantage of this change in exposure status. Additionally, such a study could be designed if there were sufficient advance warning of the cessation of military flight activity.

Such adventitious studies are difficult to plan, however, for two reasons:

- Expected decreases in noise exposure may not actually occur. For example, closing of military airbases in the past has sometimes led to alternative uses of the facilities, sometimes producing comparable or even greater noise exposure.
- Only a small percentage of the domestic MTRs and MOAs produce enough noise exposure for nearby populations to warrant epidemiologic study. Similarly, many military airbases produce less noise exposure than busy civil airports.

5.1.2.3 Relationship Between Stress and Hypertension

The general process model linking noise exposure to nonauditory health effects proposes that health effects, if any, are due to the stressful nature of noise. Experiences of stressful conditions such as noise have been linked with elevated blood pressure for short periods of time (e.g., Julius and Cottier, 1983). The notion that repeated emotional elevations of blood pressure may eventually lead to hypertension which evolved from such studies still lacks scientific support. A long term laboratory or clinical study could be designed to evaluate whether hypertension is indeed a consequence of repeated elevation of blood pressure as a result of noise exposure.

5.2 Interests of Other Federal Agencies

Half a dozen federal agencies in addition to the Air Force have interests and statutory responsibilities in effects of aircraft noise exposure. They include the U.S. Army, the U.S. Navy, the National Park Service of the Department of the Interior, the Forest Service of the Department of Agriculture, the Federal Aviation Administration of the Department of Transportation, the Environmental Protection Agency, and the National Aeronautics and Space Administration. None of these agencies currently has interests as specific or immediate as the Air Force in studies of health effects of high levels of residential aircraft noise exposure.

Glossary

Terms in this Glossary are defined in the sense in which they are used in this report, not necessarily in their broadest sense.

Case-control study: An epidemiologic study design in which subjects are selected on the basis of the presence or absence of disease and then studies retrospectively for exposure.

CHABA: Committee on Hearing, Bioacoustics and Biomechanics of the National Research Council of the National Academy of Science.

Cohort study: Study of groups of individuals (cohorts) from the same referent population who are classified on the basis of whether or not they receive exposure, and are followed to see whether or not they develop disease. Prospective cohort studies follow subjects forward in time; retrospective cohort studies follow subjects from exposure to outcome through historical records.

Confounder: A potential causal agent of disease that has not been controlled and, therefore, cannot be isolated from the presumed causal agent (exposure).

Cross-sectional Study Design: *An exploratory epidemiologic* study design in which both exposure and health outcomes are evaluated simultaneously, so that neither variable can be uniquely identified as occurring first. Cross-sectional designs produce information about prevalence rather than incidence of health outcomes, and are vulnerable to multiple biases such as selective survival.

dB: Abbreviation for decibel.

decibel: The unit for expressing the product of a constant (usually 10 or 20) and the logarithm to the base 10 of the ratio of a quantity of interest to a reference quantity.

Dosimetry: Measurement of individual noise doses in real time.

Ecologic Study: An exploratory epidemiologic research design in which the group (often a geographically defined area such as a county or census tract) rather than the individual is the unit of analysis.

Ecologic fallacy: Application of inferences about the causality of diseases in groups to individual members of groups; the assumption that outdoor noise measurements represent individual noise exposure.

Etiologic Study Designs: Etiologic study designs are those which permit inferences of causality of health effects from exposure conditions.

Misclassification bias: Misleading findings caused by incorrectly labeling of individuals with respect to disease or exposure status.

MOA: Military Operating Area.

MTR: Military Training Route.

Power: In statistics, the probability of declaring two populations different when in fact they are different.

Relative risk: The ratio of the probability of disease given the exposure to the probability of disease given the absence of exposure. In case-control studies the relative risk is estimated by the Odds Ratio (q.v.).

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